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Title : Protocols for Radiometer Deployments

Abstract : This document contains the protocols needed to maintain SI traceability in shipborne Microwave radiometers

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AMENDMENT RECORD

This document shall be amended by releasing a new edition of the document in its entirety. The Amendment Record Sheet below records the history and issue status of this document.

AMENDMENT RECORD SHEET

ISSUE	DATE	REASON FOR CHANGE
A	02/02/2021	Draft for first internal review
B	04/02/2021	Updated following comments
1	04/02/2021	Issued to ESA

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1. INTRODUCTION

This document is an update to the existing document used for IR deployments [1]. Many of the sections are simply copied from the original document and adjusted to include the special considerations that should be taken into account for deployment of Microwave (MW) radiometers.

A number of groups around the world have been measuring SST with thermal infrared radiometers (TIR) since the 1990s [2], [3], [4], and [5]. The protocols used by these groups for the measurements of SST are all similar and have been evaluated against each other at TIR inter-comparisons [6]. However, more formal versions of these protocols were only recently published by [7], [8] and [9]. In [8] and [9] they define a set of 9 protocols intended to guide any group collecting shipborne infrared radiometer data for use in satellite SST validation activities towards a “common sense” best practice that will improve the quality and reduce the uncertainty in the satellite SST validation process. Each individual deployment of a shipborne radiometer is highly specific and the protocols summarised below are considered as a minimum requirement for an in situ radiometer. The following sections reproduce the methodology of [9] and discuss some practical considerations for the implementation of the protocols.

In this version, the focus is on the deployment of a Microwave radiometer and the text contains the specific points where special considerations will have to be taken when deploying a microwave radiometer to measure the sea surface temperature. The alterations to the IR protocol are based upon the calibrations and characterization described in [10], [11] and [12] using the experience from a first static inter-comparison experiment between IR and MW radiometers [10].

2. PROTOCOLS TO MAINTAIN THE SI TRACEABILITY OF MICROWAVE SHIPBORNE RADIOMETERS

2.1 Definition of measurement methodology

The exact methodology used to measure SSTsubskin using a shipborne MW radiometer shall be fully documented. This shall include:

- A full technical description of the MW radiometer instrument (e.g. spectral characteristics, sampling characteristics, measurement technique, a description of the instrument internal calibration approach).
- The spectral characteristics of the measurement system (i.e. instrument band-pass, Polarization, H, V, Full stokes).
- A description of the applied emissivity model and the values used
- How the important geophysical parameters are estimated, such as wind speed, direction, wind direction relative to look angle, sea surface roughness, sea surface salinity and instrument look orientation with respect to solar angle.
- How the component of “sky radiance” reflected at the sea surface into the radiometer field of view is properly addressed.
- A description of the radiometer mounting arrangements and the geometric configuration of the radiometer with all measurement angles accurately documented.
- A description of steps taken to ensure that measurements are free of ship effects (e.g. ship’s bow wave, significant emission from the ship superstructure, emissions from ship exhaust plumes etc).
- A description of the steps taken to correct the polarized observations for the attitude, pitch and roll of the ship and look angle with respect to North.
- On-board instrument software used (e.g. version, release date)
- Data post processing software (e.g. version, release date)
- Any other aspect considered relevant to better understanding the quality of the measurements obtained.

2.2 Definition of laboratory calibration and verification methodology and procedures

The calibration scheme for MW radiometers varies according to the type of instrument, but typically follows the principles described in [10], [11] and [12]. It is a four-step procedure, where the first step uses the internal calibration references to calibrate up to a calibration reference at the instrument front plate. Step 2 considers the transmission lines between the antenna system and the radiometer, and step 3 accounts for the antenna system itself. Finally, step 4 accounts for the actual antenna orientation with respect to Earth North and true Horizontal/Vertical orientation. A detailed description of the validation is seen in [10].

2.3 Pre-deployment calibration verification

Following the defined methodology and procedures developed in Section 2.2, the calibration performance of a shipborne MW radiometer used for satellite product validation shall be verified prior to deployment using an external reference radiance source that is traceable to SI standards. The verification measurements should be repeated over a range of ambient temperatures representative of the instrument operating conditions and aimed at a target with realistic temperatures that are observed during deployments. Due to the low sea water emissivity values in C and X-band, it is recommended to use liquid nitrogen to perform the pre-deployment calibration. The radiometer hardware, on-board configuration, on-board processing software, and data post processing software shall not be modified in any physical way between the calibration and deployment at sea.

2.4 Post-deployment calibration verification

Following the defined methodology and procedures developed in Sections 2.2 and 2.3, the calibration performance of a shipborne radiometer used for satellite product validation shall be verified after deployment.

2.5 Uncertainty budgets

Shipborne radiometer calibration and verification data shall be linked to uncertainty budgets determined in agreement with defined National Standards Laboratory protocols (JCGM) [13] accounting for a comprehensive range of uncertainty sources (e.g. contributions from instruments, processing, deployment restrictions, and environmental conditions etc.). An uncertainty budget for the end-to-end SSTsubskin measurement shall be provided.

2.6 Improving traceability of calibration and verification measurement

Efforts should be made where possible to define community consensus schemes and measurement protocols for calibration and verification. Well-documented data processing schemes and quality assurance criteria shall be established to ensure consistency and traceability to SI standards of in situ radiometer measurements used for satellite validation. Shipborne radiometer users must participate regularly in inter-comparison “round-robin” tests and comparison with international standards to establish SI traceability for their data.

International radiometer and reference inter-calibration experiments such as those conducted for IR radiometers ([14], [15], [16], [17]) are essential experiments that should be used as inspiration for corresponding MW and MW/IR inter-comparisons and the need for regular activities of this type is obvious.

Radiometer intercomparisons should follow QA4EO principles and guidelines [18] and should include the following components:

- A laboratory-based comparison of the calibration processes for radiometers and verification of reference sources used to maintain calibration of radiometers and provide traceability to SI,
- Field inter-comparisons with IR radiometers or other MW radiometers to build a database of knowledge over several years.

The benefits of radiometer inter-comparison work include:

- Establishment and documentation of protocols and best practice for radiometer and reference inter-comparisons for future use,
- Establishment of community best practices for MW radiometer deployments,
- Evaluation and documentation of differences in MW radiometry primary calibrations and performances under a range of simulated environmental conditions,
- Establishment and documentation of formal SI-traceability and uncertainty budgets for participant reference targets and MW radiometers,
- Evaluation and documentation of protocols and best practice to characterise differences between MW radiometer measurements made in field (land, ocean, ice) operational conditions**.**

2.7 Accessibility to documentation

Documentation describing shipborne MW radiometer calibration and verification process shall be made available to the user community to promote peer review and ensure appropriate promulgation of knowledge on shipborne radiometer calibration and verification.

2.8 Archiving of data

Ship-borne radiometer calibration and verification data should be archived following good data stewardship practices providing access to records by research teams on request. Laboratory calibration and verification data shall be published in a format that is freely and openly available to users of the data.

2.9 Periodic consolidation and update of calibration and verification procedures

Shipborne MW radiometer calibration and verification measurement procedures should be consolidated as a result of a critical review of those currently documented in peer-review literature or already included in compilations produced by former projects and “lessons learned” from deployments aboard ships and in the laboratory. Consolidated protocols should be maintained and published.

3. PRACTICAL CONSIDERATIONS

This section discusses some of the practical considerations when implementing the shipborne MW radiometer protocols.

3.1 Field deployments

3.1.1 General for MW radiometers

The following considerations are valid for ship or fixed platform installations:

- Work safely. Can the mounting position be accessed safely? What extra measures are required to ensure safe working? Have you carried out a risk assessment? There is usually a legal requirement to ensure safe working and this is in any case good practice. There may be a number of unfamiliar hazards when working on ships, including: working at height, falling objects (on others below as well as on yourself), sudden movement, strong winds, slippery surfaces and difficulty communicating or attracting attention when in isolated positions.

- How much power does the instrument need? Can this power be provided by the platform (ship or fixed)?

- What wiring is needed for the instrument? Can the instrument access existing infrastructure or does specialized wiring need to be installed? If specialized wiring is needed, the platform operator may require that this be installed by their preferred contractor, which can increase lead times for the installation.

- Does the instrument need a dedicated data logging system and does the logging system need to be close to the instrument?

- If near real time data transmission to shore is needed to monitor the instrument status, the installation of a dedicated system (e.g. an Iridium modem) may be required. In some cases, this can be achieved using the platform’s existing internet infrastructure.

- Ensure that your instrument and any ancillary equipment are properly maintained. Inspect and test them before each deployment, and clean, refurbish or replace parts as required.

- Recalibrate components essential to your traceability chain (e.g. external reference thermometers) on a regular basis.

- Validate the instrument calibration immediately before and after every deployment. Do not alter the instrument in any way between the validation and deployment measurements.

- Choose a sea viewing angle that is similar to known satellite incidence angles and where reliable emissivity models exist. A common choice of viewing angle is around 55° from nadir.

- Ensure that the instrument is mounted so that it has unobstructed views to undisturbed seawater, and to the sky at the complementary angle. Confirm and record the mounting orientation.

- Avoid contamination of the measurements by exhaust and other effluents, such as hot air outlets.

- Mounting the instrument on the platform will, in general, require a specialized instrument frame or adaptor. Consider the ease of instrument installation and removal in the mounting design. If the instrument needs alignment in a frame, include alignment marks. Alternatively, use a self-aligning mount.

- When deploying, make sufficient functional tests of the instrument and ancillary equipment to ensure that data is being recorded and that at the least, any functions essential for instrument safety are operating correctly (e.g. weather protection, uninterruptable power supply). If not, remove the instrument, repair and redeploy.

- Be aware of other factors that may affect your deployment and the quality of your data. This applies in particular for RF interference from external emitters that contaminate the observations. Other factors are e.g., Sun glint contamination, window washing sprays, engine exhaust.

- Consider how to collect essential measurements, which are used to calculate the emissivity, such as: Sea surface temperature, sea surface salinity, wind speed and direction or sea surface roughness. Furthermore, SST at depth (hull or inlet sensors), air temperature, humidity, longwave downwelling radiation, water vapour and cloud liquid water can be useful additional observations.

3.1.2 Mounting on ships

For a ship-mounted MW radiometer the following points should be considered:

- The instrument should be mounted so that the sea view is of undisturbed water forward of the bow wave and the sky view is clear of obstructions (i.e. superstructure). This normally means a mounting position as far forward on the ship as practicable. Such a position should also avoid views of heated engine cooling water, which is usually discharged behind the bow wave.

- To avoid sea spray and, in difficult conditions, green water, the instrument should be mounted as high as practicable and with protection against rain and water. The mounting could be a forward instrument mast (e.g. research vessel) or the bridge roof on a vessel with a bridge near to the bow of the ship (e.g. cruise ship, passenger ferry).

- On research ships that hold station for instrument deployments or for sampling, bow thrusters can disrupt the thermal skin. In windy conditions, the ship is often oriented with the working deck or winch to windward, so that the wind does not push the ship onto the wire. As the ship is pushed downwind, water in the radiometer field of view may have passed under the hull and become mixed.

- Consider how the ship's roll and pitch modulate the emissivity of the sea surface, the polarity of the observations and the pointing of the sky view. Access to ship attitude is required, and time synchronization has to be accurate. Alternatively, the radiometer shall provide its own attitude sensor. For polarimetric radiometers (3rd stokes), the polarization aspect can be serious, as even a small angle of rotation (few degrees) will cause a dramatic change in 3rd Stokes

- If possible, during measurement campaigns install the instrument on a part of a passenger ship where passengers do not have access.

- Other installation considerations include: predominant wind direction, sun angle, possible superstructure shielding from wind, spray and the sun and the potential effects on the measurement.

3.1.3 Mounting on other platforms

Additional considerations for installations other than ships:

- The power supply might be difficult to sustain if the platform is powered by solar cells and batteries. How can the instrument be made safe if power is interrupted?
- Tidal effects should be considered before installing the instrument in coastal regions.
- Sun angle might have a bigger effect than on ships as the instrument will have the same relative position to the sun every day.
- Water may move round or under a platform, driven by tides or prevailing winds. This may disrupt its temperature structure.

3.2 Data

In addition to high level products (e.g. geolocated SSTs), always record data at the lowest level that is available (e.g. detector counts), so that it can be reprocessed if required. Where possible, record the complete state of the instrument, including internal temperatures, mechanism positions and other housekeeping data.

- In all products, always include a reliable UTC timestamp (GPS receivers are a good source), and include geolocation data or ensure that external geolocation data are available.
- Where available, use agreed data standards (e.g. netCDF, HDF5), metadata standards (e.g. CF convention, ACDD, ISO 8601) and product formats (e.g. L2R).
- Ensure that all data are recorded securely. If possible, during measurement campaigns make local secondary copies on independent media. A USB stick or SD card may be suitable.
- Assure the quality of your data. Check the format. Check any flags. Check that the data is realistic.
- Plan for the long-term archival and maintenance of your data and any associated documentation (Section 3.3). National data centres (e.g. CEDA, UK; Ifremer, France) may be appropriate.

3.3 Documentation

Document the instrument, data format, data processing methods and deployment, including:

- The spectral characteristics of the instrument.
- The emissivity model applied and the value used for seawater emissivity.

- The key values used to derive the emissivity, such as: pitch and roll, incidence angle, sea surface salinity, wind speed and direction or sea state and relative angle between incidence and wind.

- Instrument viewing geometry with respect to the Sun.

- The processing steps applied to correct V and H pol observations for effects from the Ship attitude, pitch and roll, affecting incidence angle, look angle with respect to North (relative to wind direction and Sun).

- The uncertainty model used.

- Any calibration coefficients, including those for on-board thermometers

- The SST algorithm.

- A description of the radiometer mounting arrangements and the geometric configuration of the radiometer with all measurement angles accurately documented.

- The steps taken to ensure that measurements are free of ship effects (bow wave, radiative emission from the ship superstructure, emissions from ship exhaust plumes).

- On-board instrument software used (version, release date).

- Data post-processing software (version, release date).

- Any other aspect considered relevant to better understanding the quality of the measurements obtained. Make the documentation publicly available and reference it in the data products.

3.4 Calibration sources and performance verification

- The calibration target should be capable of being operated at fixed temperatures or at a temperature that changes very slowly compared with an instrument calibration cycle (no more than a few kelvin per hour).

- The thermometric temperature of the target must be an accurate representation of its brightness temperature, or alternatively, the brightness temperature must be derived from the thermometric temperature(s) using a calibration target mathematical model with an accuracy sufficient for the calibration verification.

- The calibration target brightness temperature uncertainty must, at the most, be equal to the required verification uncertainty and preferably should be significantly smaller.

- Where possible, the instrument should be operated in the orientation and with the viewing geometry used for sea surface observations.

- All calibration measurements must be securely archived (Section 3.2).

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